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PREPARATION OF PRELIMINARY SUPPLEMENT - WRITING GUIDE FOR RELIABILITY REQUIREMENTS IN MSFC PROCUREMENT SPECIFICATIONS

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INTRODUCTION

This report presents the results of a six-week effort undertaken by ARINC Research Corporation in response to a request by Mr. H. Hill, R-QUAL-R.

Five appendices are submitted herein for use by the specification writer and others who may be concerned with the problems associated with reliability requirements. Appendix A is a proposed "re-write" of the reliability sections of document MSFC-PROC-239 of 15 June 1963 entitled "Technical Writing Guide (Specifications)". Appendix B contains explanatory material on the reliability program elements. Due to time limitations within the initial six-week study, Appendices A and B are incomplete. Recommendations for expanding Appendices A and B to provide coverage of the reliability program elements in greater detail are presented.

Additional Appendices (C, D and E) present specialized information relating to reliability requirements in procurement specifications.

CONCLUSIONS

The following conclusions were reached during this task:

1. No overall or unified set of NASA standards exists which may be used as reference sources for the specification writer. This lack of standardized reference material includes reliability program elements such as math modeling, failure mode and effects analysis and failure rate data.

2. An effective procurement specification can be written only if the specification writer has a set of rules for determining the extent to which each of the reliability program elements will be implemented. With the exception of the $1,000,000 "break point" for system procurement[1] mentioned in Implementation Circular 293, no other specific NASA or MSFC rules were encountered during the current ARINC Research study.

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1. NASA Circular No. 293 of 3 September 1963 entitled, "Integration of Reliability Requirements into NASA Procurements".

   The level at which reliability program requirements are to be placed on contractors has been redefined to include system procurements which are estimated to cost in excess of $1,000,000.

3. Some contractors are including more sections on reliability requirements in their specifications today than MSFC.

4. The role of the Reliability Assurance personnel must become increasingly more responsible in the area of procurement specifications. For example, Implementation Circular No. 293 states that "originators of procurement requests will consult as early as possible with appropriate reliability assurance personnel to determine the extent of applicability of NASA Reliability Publication 250-1".

RECOMMENDATIONS

The following recommendations are offered for consideration:

1. Modify Appendices A and B to reflect a coordinated center-wide set of reliability requirements.

2. Establish decision rules and criteria for including reliability program elements in procurement specifications. Rules should be based on considerations such as cost, criticality of the hardware current state of the art and functional level of the hardware, i.e., component, subsystem.

3. Prepare a list of standard reference specifications, manuals, and directives which each laboratory at MSFC would use during specification writing. The reference list would be similar to the list presented in Appendix C and would include a practical summary of each document together with a notation describing its application at MSFC.

4. Develop flow charts which depict the specification preparation process and the specification approval process with reference to the level of responsibility assigned to the various reliability engineering functions (particularly within the Reliability Assurance Division).

STUDY APPROACH

A meeting was held at R-QUAL-R on 31 January 1964 for the purpose of discussing two alternative approaches which were developed by ARINC in response to the task of preparing a writing guide for reliability requirements under Task 294-06 of Contract NAS8-11087. Attendees were: H. Hill (R-QUAL-R), E. Jettner and R. Braland of ARINC.

The major difference between the two approaches presented by ARINC was the depth of coverage which was programmed; one approach was scheduled as a six-week effort in contrast to a twenty-week effort for the more inclusive task.

The early promulgation of a guide for defining the reliability requirements to be included in specifications was considered by R-QUAL-R to be all important. This decision was based on the need to increase the awareness of reliability at MSFC and thereby directly influence the inclusion and coverage of reliability requirements in MSFC specifications. In accord with this short term task was initiated and ARINC Research began its study on 3 February 1964.

ARINC Research Corporation representatives who function in the capacity of NASA consultants at Michoud (Boeing) and at NAA S&ID were contacted and provided the following sample specifications for review:

S&ID Documents Reviewed

1. Spec #MC452-0026A "Switches, Power Transfer, Motorized"
2. Spec #MC284-0030A "Valve, Vent - Liquid Propellant Tank"
3. Spec #MC456-0004A "Timer, Solid State, B+ Closure, 100-Millisecond to 5 - Second"
4. Spec #MC456-0007A "Telemetry Multiplexer"
5. Spec #MC273-0031A "Coupling, Quick Disconnect, Hydraulic"
6. Spec #MC999-0003B "Documentation Requirements for Saturn S-II Suppliers"

Boeing Documents Reviewed

1. Dwg. #60B51441 "Valve Assembly, GOX Flow Control Valve and Associated Tank Pressure Simulator"
2. Dwg. #60B51004 "Duct Assemblies - Tunnel to Distributor, GOX"
3. Dwg. #60B51404 "Line Assembly - Inboard Engine, GOX"
4. Dwg. #60B83002 "Gimbal Duct Assemblies, Engine Mounted"
5. Dwg. #60B43002 "Valve Assembly, Fuel Fill and Drain"
6. Dwg. #60B00010 "General Requirements for Suppliers"

Several MSFC specifications were obtained from the Technical Documentation Section at MSFC and Mr. Hill provided a preliminary draft of the "Specification for Radio Frequency Power Amplifier 50M60034" of 20 December 1963.

On 6 February 1964 a meeting was held at P&VE with personnel of the Engineering Procedures Section (Messrs. G. Thrower, R. Smith, and J. Enoch). The purpose of this meeting was to obtain information pertaining to the format used for the writing and editing of MSFC specifications. The responsibilities of the designers and the Engineering Procedures Section were discussed. It was revealed that (in general) the responsibilities are separated to the extent that the designer provides the requirements and the technical writer presents these requirements in the correct format. The format guides which are used are MSFC-PROC-239 and DOD M-205.[3]

It was emphasized that:

1. The technical writing guide MSFC-PROC-239 was released by the Engineering Procedures Section and any revision or supplement to this document would be accomplished by the same section.

2. Any specifications which are written at MSFC must be approved by the Engineering Procedures Section to receive official status.

In addition to the above survey, a literature search was requested at the DDC (Defense Documentation Center) for the key words "reliability specifications"; one document reference was produced. An independent check at the Redstone Scientific Information Center (Documentation Section) produced a set of 35 references including a previously published ARINC Research Corporation report. All 35 references were of general interest only.

The published material and sample specifications were reviewed in order to determine how reliability requirements are currently being specified and to determine if a standard method of specification is being used. The results of this study and analysis are presented as Appendices C, D and E. Appendix C is a list of specifications which was prepared as reference material for the specification writer. Appendix D illustrates how reliability requirements are currently being placed within procurement specifications with respect to section and paragraph location. Appendix E lists detailed reliability requirement statements which were noted during this study.

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3. Manual M-205, "Military Outline of Form and Instructions for the Preparation of Specifications", dated 9 April 1958 is cancelled and superseded by Defense Standardization Manual M 200A, Notice 1, of 3 September 1962.

The following deficiencies were noted for the specifications which were reviewed:

1. MSFC procurement specifications reflect the lack of guidelines in MSFC-PROC-239 to the extent of being almost devoid of reliability requirements.

2. No standard format for specifying reliability is being followed.

3. The location of reliability requirements within specifications written by different originators shows wide variation.

The preparation of the material for the writing guide supplement was undertaken from the viewpoint of eliminating the deficiencies which are noted above.

APPENDIX A

RELIABILITY SUPPLEMENT TO MSFC-PROC-239

This appendix presents a proposed "rewrite" of the reliability portion of MSFC-PROC-239 to provide more extensive and uniform coverage of reliability provisions in MSFC specifications. The following elements of a reliability program are not included:

1. Program Management
2. Design Specifications
3. Human Engineering and Maintainability
4. Standardization of Design Practice
5. Parts and Materials Program
6. Reliability Evaluation
7. Documentation of Reliability Program

The paragraphs and examples are numbered to correspond to their locations in MSFC-PROC-239.

3.4.4.5.1 Reliability

Requirements for reliability shall be stated under this heading. The elements of a reliability program are presented in NASA Reliability Publication NPC 250-1, "Reliability Program Provisions for Space System Contractors." The integration of reliability requirements into procurement is discussed in NASA Circular No. 293 of 3 September 1963.

3.4.4.5.1.1 Reliability Statement

The required reliability or reliability goal of the equipment shall be stated under this heading in terms of probability of success or mean time to failure. The required function, environment, length and/or number of cycles of operation and specific time of operation shall be specified.

Example: The reliability goal of the R. F. power amplifier shall be 0.9999 which specifies the probability of operating successfully for 10 minutes within the environmental and performance parameters specified in the design requirements of Section 3.

The function of the amplifier is to amplify an R. F. signal, within the specified tolerances, during the prelaunch and boost phase of the S-I stage.

3.4.4.5.1.2 Failure Mode and Effect Analysis and Criticality Ranking

The requirements for a failure mode and effects analysis and a criticality ranking shall be stated under this heading. A standardized approach shall be specified for all system, subsystem, and component contractors. The scope of the analysis, documentation requirements, and format shall be specified. (For additional information, see MTP-P&VE-E-62-2* of 4 January 1962.)

Example: A failure mode, effect and criticality analysis shall be conducted on the R. F. power amplifier. The analysis shall be scheduled and performed during the early design phase and shall be used to identify all failure modes and the effect of each failure mode on the successful operation of the R. F. power amplifier.

The analysis shall consist of two parts: the failure mode and effects analysis which identifies the critical parts and the criticality analysis which ranks the critical parts.

The results of the failure mode, effect and criticality analysis shall be documented and shall be available for MSFC review. The following elements shall be considered as part of the failure mode, effect and criticality ranking format:

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*An updated version, 10M30111, is in the process of MSFC approval.

a. Item

b. Drawing Number or Part Number

c. Reference Designation

d. Function

e. Failure Type (or Mode)

f. Failure Effect for each Failure Type or Subsystem and/or System Performance, as applicable.

g. Criticality Ranking

3.4.4.5.1.3 Mathematical Modeling

The requirements for mathematical modeling shall be stated under this heading.* Math modeling consists of apportionment, prediction, and assessment.

3.4.4.5.1.3.1 Apportionment

The requirement for the apportionment or allocation shall be stated under this heading. Reliability goals shall be allocated to the individual components in order to specify the desired equipment reliability. The reliability goals shall be realistic and commensurate with the present state-of-the-art. Factors of cost, complexity, environment, and component function shall be considered.

Example: The reliability goal for the R. F. power amplifier as specified in Section 3 shall be apportioned to the component level. The contractor shall consider the relative influence of cost, complexity, environment, and type of function.

The technique and analysis shall be documented and made available for MSFC review.

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*Apportionment and allocation are used as synonyms in this report.

3.4.4.5.1.3.2 Prediction

The requirement for a reliability prediction shall be stated under this heading. The contractor shall be required to develop a prediction model early in the design stage. The failure rate information which is to be used shall be specified in this section.

Example: A reliability prediction model shall be prepared for the R. F. power amplifier. The model shall include a functional diagram showing the operational modes and redundancy of the components that make up the amplifier. The source of failure rates and environmental and application factors shall be established in conjunction with MSFC. The appropriate statistical distribution functions shall be used.

The contractor shall compare the predicted values of reliability for the components and system to the reliability values which were allocated during the apportionment. If the predicted values are less than the allocated values, these discrepancies shall be presented at the reliability design review with suggestions for redesign or other action.

The analysis and technique shall be documented and made available for MSFC review.

3.4.4.5.1.3.3 Assessment

The assessment of achieved reliability and the level of confidence, if applicable, shall be stated under this heading. Assessment shall be required at specified milestones of the manufacturing and test phase as test or failure data become available. Data documentation requirements shall be defined in the procurement specification.

Example: The contractor shall assess the achieved reliability of the R. F. power amplifier at the end of the manufacturing phase and during the test phase. The data used shall consist of test data. Failure rate information shall be used to supplement test data for assessments performed before all tests have been completed.

Discrepancies between the assessed reliability and the allocated and predicted reliabilities shall be resolved during design review.

The analysis and technique shall be documented and be available for MSFC review.

3.4.4.5.4 Reliability Design Reviews

The requirement for reliability design review shall be stated under this heading. At least three design reviews should be performed during a development cycle involving design changes, depending upon the complexity of the item. The design reviews shall be specified as:

1. Preliminary design review - early in the design phase.

2. Intermediate design review - prior to initial design completion.

3. Final design review - prior to final design release.

The requirement for a reliability representative as a member of the design review committee shall be specified. The reliability factors to be considered during the design reviews shall be defined.

> Example: The contractor shall schedule and conduct reliability design reviews during the development phase of the R. F. power amplifier. The reliability design reviews which shall be held are:
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> 1. Preliminary design review - This review shall be held early in the design phase. The results of the failure mode and effects analysis, the criticality ranking and the mathematical apportionment of the reliability goal shall be considered in determining the most feasible and reliable design.

2. Intermediate design review - This review shall be held prior to initial design completion, but after drawings and specifications have been prepared. The results of the prediction model, a comparison between the predicted and apportioned values, failure effects, part failures, reliability demonstration test plans and component and parts selection shall be reviewed at this time.

3. Final design review - This review shall be performed prior to final design release when final drawings and specifications have been prepared. The compatibility of the design with the reliability requirements, comparisons of assessed values to predicted and apportioned values, reliability demonstration test plans, component and part selection, and tolerance analysis shall be considered during this review.

The design review committee shall have a representative from reliability engineering, who shall be responsible for assuring that the reliability requirements are met.

The design reviews shall be documented and shall present the results of the review, the actions assigned, and the scheduled completion date of the actions. The design review reports shall be available for MSFC review within twenty-one days after the design review date.

3.4.4.5.5 Reliability Demonstration Test

The requirements for a reliability demonstration test, if applicable, shall be stated under this heading. The following factors shall be specified or required from the contractor:

(a) General type of test plan

(b) Number of items to be tested

(c) Test duration

(d) Test conditions, including environmental factors

(e) Parameters of performance and conditions of successful operation

(f) Contingency plans for use in the event of test failure, including provisions for retesting, waivers, and modifications.

(g) Specific test objectives, including a statement of reliability numerics and level of statistical confidence, if applicable.

Example: The contractor shall conduct reliability demonstration tests on new R. F. power amplifiers of a design which is identical to the R. F. power amplifiers that have successfully passed the production tests and qualification tests which are specified in Section 4.

The contractor shall submit to MSFC a detailed reliability demonstration test plan at least sixty days prior to the scheduled start of testing. The test plan shall be designed for testing a minimum of five R. F. power amplifiers each of which must operate successfully for a minimum of 766 hours with no failure. The plan shall contain detailed test procedures, test schematics, including all instrumentation and control equipment, and shall completely specify the test objectives. Methods shall be included to cover the event of failure, retesting, and modification.

Written approval of the test plan must be granted to the contractor by MSFC prior to test initiation.

3.4.4.5.6 Failure Reporting and Corrective Action

The requirement for failure reporting and corrective action shall be stated under this heading. The contractor shall be required to report to MSFC all failures that occur in-plant, at test sites, or at installation sites. The contractor shall be required to conduct an analysis to determine the cause of the failure and the corrective action required to eliminate the cause of failure. Requirements for failure reporting forms and the corrective action forms shall be defined in the specification.

Example: A detailed report shall be made by the contractor on each failure that occurs in-plant, or at installation site, or at test sites. The contractor shall conduct an analysis to determine the cause of the failure and the corrective action to eliminate the cause of failure.

The failure reporting form shall be provided by the contractor and include, as a minimum, the items listed in Mil-R-27542. The corrective action form shall contain, in addition to a description of the article, the cause and effect as determined by the failure analysis, the recommended corrective action, and the analysis techniques used.

A summary of all failure activity shall be prepared and forwarded to MSFC on a monthly basis. The failure reports and corrective action forms shall be available for MSFC review.

3.4.4.5.7 Equipment Logs

The requirements for equipment logs shall be stated under this heading. The contractor shall submit a proposed format for equipment logs to MSFC for approval. The specific requirements for equipment logs are presented in detail form in NASA Reliability Publication NPC 250-1, Section 3.10.

Example: The contractor shall prepare a detailed equipment log for each R. F. power amplifier. The log format shall be prepared and submitted to MSFC for approval at least sixty days prior to manufacturing.

The following minimum information must be included as part of the proposed log:

(a) Date and time of entry

(b) Identity of test or inspection

(c) Environmental conditions

(d) Characteristics being investigated

(e) Parameter measurements

(f) Accumulated operating time

(g) Discrepancies between the item tested and pertinent specifications or drawings

(h) Repair and maintenance record

(i) Action taken to have "quick fixes" in test formalized as design changes

3.5.5 System and Subsystem Specifications

Contractors shall establish and maintain an effective quality program to satisfy minimum requirements of the procuring activity. Applicability of NASA Quality Publications NPC 200-2 and NPC 200-3 shall be determined on the basis of each separate contract or order. As a minimum, NASA Quality Publication NPC 200-2 shall apply to stage contractors, engine contractors and their major subsystem contractors as determined by the procuring activity. NASA Quality Publication NPC 200-3 shall apply to contractors supplying space materials, parts, components, and services to a prime contractor or directly to the procuring activity. Detailed implementation of these quality assurance provisions shall be as outlined in the quality program plan required by NASA Quality Publication NPC 200-2, or the supplier's inspection plan required by NASA Quality Publication NPC 200-3, as applicable.

Contractors shall establish and maintain effective reliability programs to satisfy minimum requirements of the procuring activity. Applicability of NASA Reliability Publication NPC 250-1 shall be determined on the basis of each separate contract or order.

The following general guidelines or objectives are excerpted from NASA Circular 293 of September 3, 1963:

(a) Reorient reliability provisions in existing procurement regulations toward reliability assurance rather than reliability monitoring;

(b) Detail the application of NASA Reliability Publication "Reliability Program Provisions for Space Systems Contractors" (NPC 250-1); and

(c) Redefine the level at which reliability program requirements are to be placed on contractors as system procurements estimated to cost in excess of $1,000,000, rather than development projects estimated to cost in excess of $5,000,000.

In applying NPC 250-1 to existing contracts, cognizant personnel will exercise discretion to prescribe only those program requirements still considered timely in light of project completion status and to prescribe them to the extent where anticipated benefits are considered to be commensurate with cost.

For procurements of $1,000,000 or less where the contractor has design responsibility for a space system or for critical hardware end items or equipment to serve as part of a space system (including critical test equipment), the cognizant NASA/MSFC personnel will determine and impose selected applicable reliability program requirements (e.g., reliability design review, failure analysis).

APPENDIX B

THE MEANING OF RELIABILITY REQUIREMENTS FOR PROCUREMENT SPECIFICATIONS

The following section contains background information to support and to explain the need for the requirements which are specified in Appendix A. This material is not included in the writing guide supplement because it is of an explanatory or tutorial nature. It is included here in order to provide a convenient reference source to the specification writer.

1) <u>The Role of Reliability in Procurement Specifications</u>

A specification is an essential item. At MSFC, a specification is a document intended primarily for use in procurement. Further, a specification must clearly and accurately establish and describe the technical requirement for a component, subsystem or system including the methods of inspection for determining that the requirements have been met.

For programs with high reliability requirements such as the Saturn program, specifications assume a role of utmost importance because time devoted to clarification or misunderstanding is lost time. Good specifications reduce errors, and good reliability requirements help produce good specifications.

The reliability requirement portions of current specifications suffer from one or more of the following faults:

1. Lack of clarity
2. Incompleteness
3. Lack of feasibility

All of the above attributes have a deterrent effect on specifying the desired reliability.

Manuals M-205[a] and MSFC-PROC-239 present a standardized format for use with all types and classes of specifications. These manuals contain instructions on style and structure, as well as information on the major sections of the specification.

It is apparent that the principal sections of a specification are the ones concerning requirements and quality assurance provisions. The contents of these sections cause the majority of the problems which arise in the writing, or use, of specifications.

Reliability is an inherent characteristic which must be designed into a piece of equipment. The numerical reliability requirement must be specified along with other requirements in order that it may be considered throughout design. However, a numerical reliability requirement is not sufficient in itself to specify reliability.

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a. More recently, Manual M-200A.

Reliability is the probability that a system will perform satisfactorily for at least a given period of time when used under stated conditions. This definition requires that additional information be made available in order to make a numerical reliability requirement meaningful.

The function of the device must be adequately specified, the operational time period indicated, and the operating conditions described. If this information is not available, specifying a numerical reliability requirement cannot be meaningful. The adequacy of the engineering information contained in a specification must be ascertained before the reliability section is written.

In fact, the sections relating to preferred parts, general design information, requirements for identification, workmanship requirements, and even the sections on preparation for delivery can seriously affect reliability.

The following paragraphs are written to help explain why concepts such as math modeling and failure mode and effects analysis are included as reliability requirements. The careful specification writer will work closely with the design engineer and the reliability engineer during the preparation of the reliability requirements.

Assistance is available to the specification writer from sources other than MSFC-PROC-239. The Reliability Assurance Division can participate in the planning of the specification writing task, offer assistance in writing the reliability and environmental portions of each specification, and review each specification prior to release.

2) Reliability Statement

A design parameter which is needed before any design effort is expended is the numerical value of the overall reliability objective or goal of the component, subsystem or system. This value is formulated by MSFC and consists of a number such as 0.9999 which specifies the "target" value of the reliability of a system or the required reliability which must be demonstrated.

If a "target" or goal reliability is specified, the contractor is informed by means of the goal statement which defines the system or hardware configuration to which it applies.

An alternative method of writing the reliability statement is in the form of a requirement as, for example, a statement that the contractor shall demonstrate that the hardware has achieved a reliability of 0.9999. If the statement is expressed in this form, a follow-on provision must be made elsewhere in the procurement specification to indicate how the achieved reliability is to be demonstrated as, for example, by means of a demonstration test. If the numerical reliability requirement is stated, the assignment should precede the contractual work on the design of the system.

An unrealistic requirement is detrimental because:

1. If the requirement is high, the expenditure of money and time for development and production will be greater than necessary; and further, it may not be possible to design and build the hardware within the present state of the art.

2. If the requirement is low, the acceptable product may not function properly when required.

3) Failure Mode and Effect Analysis (FMEA) and Criticality Ranking

After the design of a component, subsystem, or system has been established an important question that often remains to be answered is: In how many different ways could the hardware which is represented schematically by the design drawings fail and further, exactly what would be the effect of this failure upon the successful completion of the mission for which this piece of equipment was designed. A powerful tool available to the design engineer and the reliability engineer which is used to answer this question is called the failure mode and effect analysis. An important part of the FMEA is the criticality ranking whereby the items which contribute to failure are ranked by their relative level of importance.

The method by which a failure effects analysis is completed requires the design engineer and the reliability engineer to analyze the system and to identify the different modes of failure of the parts or components.

A thorough and systematic study is required in order to assure that no important failure modes have been omitted. It is only after the failure mode and effect analysis is completed that the reliability engineer can start a criticality analysis in order to determine the probability of system failure associated with each of the critical parts.

It is important to generate the FMEA and the criticality analysis as early in the development program as possible so that potential problem areas in reliability and/or design may be determined before the overall schedule is jeopardized.

FMEA consists of identification of critical items, and criticality ranking of system components. The analysis leading up to the identification of critical items consists of:

1. Drawing symbolic logic block diagrams
2. Identifying all system components
3. Completing failure effect analysis
4. Preparing critical items list

The analysis leading to the criticality ranking consists of ranking all components based on the applicable failure mode, the probability of vehicle loss, the failure mode frequency ratio and the unreliability.

In order to standardize the FMEA documentation by contractors, the following elements shall be specified as part of FMEA format:

1. Item
2. Drawing number
3. Reference designation
4. Function
5. Failure type (or mode)
6. Failure effect for each failure type on subsystem and/or system performance, as applicable
7. Criticality ranking

4) Mathematical Modeling

1. General

Mathematical analysis is used in conjunction with the reliability model, input data on failure probabilities, and test results to:

(a) Establish reliability goals down to the component level at different development and production milestones by the use of apportionment techniques.

(b) Predict ultimate reliability at different design milestones by use of prediction techniques.

(c) Formulate test plans.

(d) Assess achieved reliability at different production and test milestones (and establish the mathematical confidence limits attained, if applicable).

2. Reliability Model

A reliability model is an equation or a diagram which represents the success modes or the failure modes of the system in terms of subsystem success or failure modes. Different kinds of system success (for instance, crew survival or successful execution of alternate missions) are usually represented by separate models.

The reliability model is usually based upon the failure mode and effect analysis described in Paragraph (3) above. No part or component failure mode is omitted from the model unless its probability of occurrence is small.

A part or component failure mode may be considered to have a small probability of occurrence if the probability of this mode occurring anywhere in the system during the test sequence or mission can be shown to be two orders of magnitude smaller than the average of the probabilities of occurrence of the other failure modes. Failure modes with small probabilities of occurrence are usually neglected in the model. For example, if the average failure probability is 0.0001, then any failure mode with a probability of occurrence of 0.000001 or less would be ignored.

3. Apportionment

Reliability apportionment is a method of distributing to the lowest applicable level of elements the reliability which is allocated according to the state-of-the art and potential capabilities of each element (subsystem or component). These reliability values are then used for establishing design objectives, and serve as a basis for programming development effort.

Apportionment is the reliability technique whereby reliability is established as a design parameter. Reliability requirements and methods of demonstrating compliance with them must be specified in each contract. In some cases it may not be practical to demonstrate compliance because of economic limitations, schedules, etc. The allocation of reliability during the initial stages of system design permits reliability to be specified and provides a basis upon which demonstration and acceptance tests can be prepared and costed.

The techniques of apportionment require that a general reliability mathematical model has been developed. The model incorporates those factors which have a direct and important bearing on achievable reliability of components, subsystem, and systems. The factors include:

System and failure definitions

System reliability requirements

Design characteristics of the system

Unit/system failure relationships

Duty cycles and operating requirements

The allocation process by itself gives no assurance or guarantee that the reliability so assigned will materialize in service operation of the system. The allocation procedure takes an assigned overall reliability and apportions the allowable unreliability to the various units of the system. If the system reliability requirement exceeds the state-of-the art, each unit allocation will reflect its appropriate share of the required increase in the state-of-the art.

The allocations arrived at can be further modified through study of trade-offs between reliability, other performance requirements, weight and space, calendar time, and monetary limitations. The initial allocation is made on the basis of factors which can be quantified at the time of the initial design. The following list contains many of the factors which, to various degrees, are important in allocation.

Basic Objective

System reliability requirement
Feasibility of the requirement

Unit Capability

State-of-the art
Complexity

Failure Characteristics

Failure definitions
Failure relationships
Failure modes
Failure distributions
Environmental and stress relationships

System Design

Redundancy
Duty cycles
Environmental conditions

4. Prediction

Prediction is the process whereby the mathematical model which represents the success or failure modes of the system is evaluated with data to produce a computed numerical estimate of the system reliability. The computed numerical estimate of the system reliability is the probability that the system will perform satisfactorily for at least the given period of time when used under the stated conditions.

Prediction requires that an FMEA or similar document be available from which to develop the mathematical model. In addition, some standard or consistent set of failure information of a generically similar nature must be available for parts, components, or subsystems.

From the preliminary design release of a hardware configuration, a first forecast of the hardware reliability can be made using the techniques outlined above. After the numerical evaluation is completed, an analysis of the system problem areas is made. The analysis is directed toward detecting potential unreliability.

The analysis is usually performed by a reliability engineering group who may recommend alternative configuration as, for example, redundant paths or simplified design, which would reduce the system failure probability.

The development of a reliability prediction includes the following steps:

(a) A complete review of the system design is made to determine its primary physical and functional components and subsystems.

(b) A functional breakdown of the system is used to construct a reliability model for each subsystem. These reliability models are usually simplified diagrams which depict interdependencies of all the subsystems or parts comprising the system, and correspond to the failure modes shown in the FMEA.

(c) The assignment of a probability of failure is made for each failure mode. The probability of failure is calculated from failure data compiled from tests on similar parts used under similar environmental conditions. Adjustments to reflect environments, application and essentiality are made as required by the use of adjustment factors (such as K factors).

(d) Component reliability values are combined according to the functional relationships of all parts of the system, in order to predict an integrated reliability estimate for the system. Functional interdependencies, system redundancy, and component-function criticality are considered in this step.

In summary, the method of prediction requires substituting the individual probabilities of failure into the reliability model. Probabilities of failure should be based on failure rate data and operating time required by the element during the mission and the environmental conditions anticipated for the element during this time. Environmental conditions may include those during the test and installation sequence as well as during the mission.

If failure rate tables and K factors are used to obtain the failure probabilities, such rates and K factors should be subject to prior MSFC approval.

5. Assessment

Reliability assessment is the determination of the degree of reliability actually attained in the development program. It is in effect a measurement of the reliability which has been attained at the date of the assessment. The assessment of the achieved reliability of stage, systems, subsystems, components, and parts is usually made preceding each major milestone. Assessment data will include both forms below:

(a) Test data from the development program

(b) Test data and additional failure probability information from other similar equipments

The testing used for demonstration of the system, subsystem, component, or part reliabilities will vary considerably. In some cases, a very refined sampling plan and sequential testing program will be utilized; in other cases, the results of development testing must be reviewed for assessment of the reliability. A complete understanding and review of the test data produced, the problems experienced in the test program, and a close examination of design changes to correct the failure which occurred, is needed to formulate the assessment of the achieved reliability.

The reliability assessment is compared to the allocated and predicted values in order to measure progress, determine data deficiencies, and to identify reliability problems and to develop trade-offs with other design parameters.

5) Design Reviews

A design review is a formal review or audit of the design of a product to determine whether a product is capable of meeting its performance requirements. The purpose of a design review is to subject the design to a complete examination including component applications and design factors such as reliability, cost, and fabrication. The design review allows the product to be evaluated by personnel other than the designer--those of widely different backgrounds and experience in specialized areas. Design reviews are conducted by a committee appointed by management; members are representatives of various pertinent engineering disciplines.

The design review committee will normally consist of a chairman and representatives from design, reliability, systems engineering, testing, quality control, and manufacturing. Each design review may require different types of personnel as committee members, depending upon the nature of the product.

The chairman of the design review committee is responsible for conducting the design review and assigns responsibility for resolving technical problems and preparing the design review report. The design review report lists the problem areas, the recommended actions, to whom the actions are assigned, and the date the action is to be completed. The corrective action is reviewed by the chairman after the action item has been completed.

The number of design reviews scheduled will depend upon the product under consideration. In some instances, only one or two design reviews are necessary; in other cases, a development cycle may involve major design changes which necessitate several design reviews. It is common for a contractor to schedule at least three design reviews for a product during its development cycle. A typical schedule would consist of the following reviews:

1. Preliminary Review - This type of review is usually performed early in the design phase. The system or component is reviewed to insure that all possible failures and environments have been considered and that the proposed design will accomplish the desired results. The proposed designs must be feasible from an operational aspect, as well as from the production standpoint.

2. Intermediate Review - This review takes place prior to initial design completion, but after drawings and specifications have been prepared. The intermediate review considers the analytical studies forming the basis for the design and the detailed layout of the product. The compatibility of the component characteristics with the system is reviewed as to the effect of malfunctions, failure or performance decline of each part. Fabrication problems are reviewed and alternate designs are recommended if necessary.

3. Final Review - This review is performed prior to release of final drawings and specifications which will be used for procurement of hardware. The final review considers the problems of layout, construction, fabrication, maintenance, design practices, and compatibility of design with reliability and performance requirements.

A list of typical items for discussion during a design review is:

1. Tolerance studies
2. Parts application
3. Reliability apportionment, prediction, and assessment
4. Failure mode, effect and criticality analysis
5. System concept and alternative approaches
6. System performance
7. Compatibility of equipment
8. Stability of system
9. Cost aspects
10. Ease of fabrication
11. Interference problems
12. Ease of maintenance and service
13. Documentation associated with design
14. Changes
15. Environmental effects
16. Test data
17. Trade-off studies
18. Redundancy

An important phase of a design review is the documentation of the results of the review, the actions assigned and the scheduling of these actions. A report of the design review should be issued as soon as possible to all activities concerned with the design. The design review report states the results of review, as well as the history of the events and problems which occurred during the development and production of the product.

The reliability engineering group should be represented on the design review committee. The representative is responsible for insuring that all reliability requirements are met.

The results of the failure mode and effect analysis, the criticality ranking and the mathematical apportionment of the reliability goal are important considerations during the design reviews. These results are used to designate critical reliability areas in the proposed design and to pinpoint areas where alternate designs may be used to improve the reliability.

The results of the prediction model are contributory to the design reviews. The effects of malfunctions are considered. Part failures are reviewed and compared with the goals which were apportioned, and suggestions for redesign or other action should be considered at this time. Reliability demonstration plans and component and part selection plans are reviewed, as are the results of worst-case or tolerance analyses and other detailed reliability analyses.

The compatibility of the design with the reliability requirement is reviewed during the design reviews. The results of the prediction and assessment model, as compared with the apportioned goals, are reviewed as are any suggestions for redesign to increase reliability.

6) Reliability Demonstration Testing

The reliability demonstration test is one of the important reliability checkpoints and must, therefore, be carefully formulated by the specification writer.

Depending upon who will originate or formulate the detailed requirements for testing and how the requirements will be considered from the viewpoint of overall objective, several alternative approaches to testing are available. The level of complexity of the specified hardware, e.g., component, subsystem, or system will also influcence the choice of one of several alternative approaches which are available to the writer. Each alternative must be judged against a set of values which depend upon design engineering judgment, the risks which the MSFC is willing to assume, and trade-offs involving relationships between cost and schedule, cost and reliability, and cost and assurance. In certain cases, it may not be practical to specify the requirements for reliability demonstration testing.

It is, therefore, necessary to consider whether MSFC will specify the detailed test requirements as part of the procurement specification, or whether this function will be delegated to the contractor with the proviso of subsequent submission of detailed test plan for review and/or approval.

In any event, the following factors are all important to the formulation of a reliability demonstration test plan:

Hardware Item(s) - Specify exactly which hardware items or combinations thereof are to be tested. Regardless of the test objective, mention must be made of the number of units to be tested.

Test Schedule - Specify when the items are to be tested in relationship to the program plan. If the contractor is required to develop his own test schedule, specify (a) whether or not MSFC approval or review action is required before proceeding with the test, and (b) when the contractor should submit the schedule for MSFC action.

Test Design	-	Specify the test objectives such as a demonstrated MTBF and include, if possible, the expected test time. For statistically designed tests, include the level of confidence and the test hypothesis.
Test Procedures	-	Specify the definitions of valid and invalid test data, the environmental and operational stresses which are to be included, the type of test monitoring which will be used and any special considerations which arise as a result of designing for reliability: redundant circuits, stand-by operation, etc. Tests should be conducted under mission environments to the maximum practical extent. Selection of natural environments should conform to Apollo System Specification M-DE 8000.001 and the Natural Environment and Physical Standards Specification M-DE 8020.008.
Excluded Items	-	Specify if any items which normally would be included in the reliability demonstration test are to be excluded from the test plan. State justification.
GFE	-	Specify the extent to which government furnished equipment will be required for the conduct of the test.
Pre-Test Summary	-	Specify if the applicable history and methods of prior tests are to be referenced or incorporated in the test plan.

It is emphasized that the specification writer cannot begin to write this section until he has:

1. Obtained functional description of the equipment.

2. Determined the selection of test environments and their severity.

3. Determined a set of criteria which are mutually accepted by the customer and the producer. These criteria should state the parameters which are necessary to assure satisfactory equipment functioning, the limits on these parameters, and the methods of determining failure.

4. Determined whether a test plan will be statistically oriented or developed along the lines of assuring maximum engineering confidence.

5. Developed alternative methods for testing in the event that the demonstration test is a failure.

6. Determined the degree of review and/or approval required by MSFC before the test plan is implemented and the schedule for such action.

In the case that statistically designed test plans are considered, it must be emphasized that these test plans require decisions to be made beforehand relating to the degree of risk assumed by the producer as well as the customer. The specifications must provide rules for accepting or rejecting the claim that the contract specified reliability parameters, e.g., MTBF, has been verified statistically.

Other test procedures are currently being developed which de-emphasize the amount of test data accumulation in favor of emphasizing the degree of engineering confidence or reliability assurance which is established during the early design and development phase. These schemes are based on demonstrating that the system, subsystem, and the component has been designed in such a manner that failure has been "engineered out". This consideration emphasizes the design proof tests, the design review, and the pretest analysis, the off limit test, and the evaluation of strength variances. When using these approaches, it is important to establish definitions for the mission cycle or the equivalent mission life, and, as in the previous discussion, have completely defined the criteria for demonstrating the reliability goal.

7) Failure Reporting and Corrective Action

The success of any reliability engineering work depends on maintaining adequate records from which data may be summarized relating to past failures and their causes.

The data problem presented by reliability engineering is usually defined in negative terms with emphasis on the items that failed, the mode of failure, the human errors involved, and the control actions which must be taken to prevent recurrence of this mode of failure. This general reliability area may be called the control of recurrent failures.

To be effective, failure recurrence control must be based on a system of data collection, reporting and analysis, which identifies and describes the underlying cause of failure.

In order to exercise effective control of failure phenomenon, five program ingredients are necessary: failure reporting, failure analysis, failure diagnosis, corrective action, and follow-up. In general, these five ingredients may be considered by applying the following eleven steps:

1. Observation of the failure or malfunction.
2. Preparation of the trouble-and-failure report.
3. Analysis of the failure and its effects.
4. Assignment of responsibility for corrective action.
5. Preparation and distribution of the reliability problem notice.
6. Investigation of the problem by the cognizant activity followed by a determination of a corrective action.
7. Corrective action review.
8. Design and engineering change review.
9. Implementation of corrective action.
10. Retesting of the equipment in which trouble originated to verify the adequacy of the correction.
11. Preparation and distribution of summary report to cognizant design groups.

Failure reporting, analysis, and correction have commonly been provided for in the past, and in many cases today, in the Quality Assurance provisions section of the procurement specification. The NPC 200-2 and 200-3 (in Sections 14.1 and 3.13, 3.14, respectively) present some of the considerations of failure reporting. More recently, the NPC 250-1 in Section 3.7 (Reliability Program Provisions for Space System Contractors) has provided a requirement for failure reporting, analysis, and correction.

A comprehensive system for failure reporting requires that all pertinent reliability data pertaining to a given part or component be recorded adequately and accurately in order to furnish a means for problem detection and to prevent "forgotten" problems. In the interest of tracing failures, each failure report should be unique (have an individual serial number) and should forward data on only one failure, rather than multiple failures. Exact description of the part and/or component should be required on the form in order to provide facts for subsequent reliability analysis. These facts include operating time or time of failure, type of malfunction observed, and reference to physical location in the system.

The following items are usually required on a failure reporting data form:

1. Report Number
2. Initial Report Number
3. Reporting Contractor
4. Work Center or Department
5. System Type, Model, Series
6. System Serial Number
7. Equipment Type, Model Designation, Model Number
8. Equipment Serial Number
9. Failed Item Part Number
10. Failed Item Serial Number
11. Failed Item Name (Noun)
12. Failed Item Manufacturer
13. Failed Item Designation
14. Next Assembly Part Number
15. Next Assembly Serial Number
16. Next Assembly Name
17. Next Assembly Manufacturer
18. Next Assembly Reference Designation

19. Replacement Part Number
20. Replacement Serial Number
21. Subsystem
22. Date of Failure
23. Operational Usage at Failure of Removal
    a. Total Time/Cycles/Miles/Calendar Time
    b. Standby or Operation and Environment
24. Total Age of Item
25. Activity during which Failed Item Discovered, e.g., Calibration, Checkout, Countdown, Launch, Preflight, etc.
26. Initial, Subsequent, and Final Disposition
    a. Condemned
    b. Repaired
    c. Found Serviceable
27. Effect of Failure
    a. Mission Failure
    b. Performance, Degradation
    c. No significant Effect
28. Type of Failure (primary, secondary)
29. Cognizant Action Agency
30. Analysis Required (yes - no)
31. Narrative description of trouble (how malfunctioned)
32. Failure Analysis Report Number (if required)
33. Disposition Approval Signatures

8) Equipment Logs

Equipment logs are a valuable source of data which completcly specify the continuous history of a component, subsystem, and system throughout the development, inspection, test, and operational phase prior to launch. The logs provide records of accumulated operating time (or number of cycles) associated environmental conditions, failure observations, and unsatisfactory conditions.

The requirements for a complete set of equipment logs are stated in Paragraph 3.10 of NPC 250-1 as follows:

1. Data and time of entry
2. Identity of test or inspection
3. Environmental conditions
4. Characteristics being investigated
5. Parameter measurements
6. Complete identification of instrumentation used, including serial number and calibration data
7. Failure observation and failure report reference
8. Accumulated operating time
9. Cumulative number of duty cycles to date
10. Deviation from specifications or drawings
11. Repair and maintenance record
12. Record of pertinent unusual occurrences involving the equipment
13. Action taken to have "quick fixes" in test formalized as design changes

9) Excluded Items

The following elements of a reliability program have been excluded from this report due to time limitation only:

1. Program management
2. Design specifications
3. Human engineering and maintainability
4. Standardization of design practice
5. Parts and materials program
6. Reliability evaluation
7. Documentation of reliability program

(It is recommended that these items be reviewed and discussed for possible inclusion in this appendix.)

APPENDIX C

LIST OF SPECIFICATIONS RELATING TO RELIABILITY REQUIREMENTS

This appendix contains a listing of government and associated documents relating to reliability requirements.

1. Reliability Program Specifications

a. NPC-250-1 (NASA)	Reliability Program Requirements
b. MIL-R-27542 (1) (USAF)	Reliability Program Requirements for Aerospace-Systems, Subsystems and Equipment
c. WS-3250 (WEPS)	Reliability General Specification
d. MSFC-PROC-239	Technical Writing Guide - Specifications

2. Reliability in Design, Development, and Production of Equipment and Subsystems

a. MIL-R-26474 (USAF)	Reliability Requirements for Production Ground-Electronic Equipment
b. MIL-R-27070 (USAF)	Reliability Requirements for Development of Ground Electronic Equipment
c. MIL-R-27173 (USAF)	Reliability Requirement for Electronic Ground Checkout Equipment
d. MIL-R-26484A (1) (USAF)	Reliability Requirement for Development of Electronic Subsystems for Equipment
e. MIL-R-55231 (1)	Reliability Requirement General for Production Electronic Equipment
f. MIL-R-22256 (WEPS)	Reliability Requirement for Design of Electronic Equipment or Systems
g. MIL-R-22732A (Ships)	Reliability Requirement for Shipboard and Ground Electronic Equipment

3. Reliability Organization, Monitoring, Assurance, etc.

a. MIL-R-22973 (WEPS)	Reliability Index Determination for Avionic Equipment Models, General Specification for
b. MIL-R-26667A (2) (USAF)	Reliability Longevity Requirements Electronic Equipment, General Specification for
c. MIL-STD-441 (DOD)	Reliability of Military Electronic Equipment
d. MIL-R-23094A (WEPS)	Reliability Assurance for Production Acceptance of Avionic Equipment, General Specification for
e. MIL-M-9933 (1) (USAF)	Maintainability and Reliability Program Quick Reaction

f. MIL-R-19610 (WEPS)	Reliability of Production Electronic Equipment General Specification for
g. SPEC-BLTN-506 (USAF)	Reliability Monitoring Program for Use in the Design, Development, and Production of Air Weapon Systems and Support Systems
h. MIL-STD-721A (DOD)	Definition of Terms for Reliability Engineering
i. MIL-STD-756A (DOD)	Reliability of Weapons Systems, Procedures for Prediction and Reporting Prediction of

4. <u>Detail Requirements</u>

a. <u>Data</u>

1. MIL-D-9310B (2) (USAF)	Data for Aeronautical Weapons Systems and Support Systems
2. MIL-D-9412D (2) (USAF)	Data for Aerospace Ground Equipment (AGE)
3. MIL-D-26239A (USAF)	Data Qualitative and Quanitative Personnel Requirements Information
4. MIL-D-70327A (2) (DOD)	Drawings, Engineering and Associated List

b. <u>Design</u>

1. MIL-STD-439B (1)	Electronic Circuits
2. MIL-E-4158C (USAF)	Electronic Equipment Ground General Requirement for
3. MIL-E-5400F (ASG)	Electronic Equipment, Aircraft General-Specification for (ASG)
4. MIL-E-8189B (1) (ASG)	Electronic Equipment, Guided Missiles, General Specification for
5. MIL-W-9411A (2) (USAF)	Weapon System, Aeronautical General Specification for
6. MIL-E-16400E (2) (NAVY)	Electronic Equipment, Naval Ship and Shore, General Specification
7 7. MIL-E-19600A (WEPS)	Electronic Modules, Aircraft General Requirements for
8. ANA-BLTN-444	Electronic Equipment, Piloted Aircraft, Design Criteria for
9. AD-114274	Reliability Factors for Ground Electronic Equipment
10. AD-148556	Philosophy and Guide Lines for Reliability Prediction Ground Electronic Equipment
11. AD-148907	Handbook of Methods of Cooling Airforce Ground Electronic Equipment

c. Environmental Factors

1. MIL-STD-210A (1)	Climatic Extremes for Military Equipment
2. MIL-T-152B (1) (DOD)	Treatment, Moisture and Fungus-Resistant of Communications, Electronic, and Associated Electrical Equipment
3. SPEC-BLTN-106A (USAF)	General Environmental Criteria for Guided Missile Weapon System
4. SPEC-BLTN-115 (1) (USAF)	Environmental Criteria for Ground Support Equipment
5. SPEC-BLTN-523 (USAF)	Space Environmental Criteria for Aerospace Vehicles
6. MIL-STD-446A	Environments for Electronics Parts, Tubes and Solid State Devices
7. M-DE-8000.001	Apollo System Specification
8. M-DE-8020.008	Natural Environment and Physical Standards Specification

d. Equipment Types

1. MIL-STD-243	Types and Definitions of Models for Communications-Electronics Equipment

e. Enclosures

1. MIL-STD-108D (1)	Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment
2. MIL-C-172C-1D (DOD)	Cases, Bases, Mounting, and Mounts, Vibration for use with Electronic Equipment in Aircraft
3. MIL-E-2036C (4) (NAVY)	Enclosures for Electric and Electronic Equipment, Naval Shipboard

f. Human Factors

1. MIL-STD-803	Human Engineering Criteria for Aircraft, Missile, and Space Systems, Ground Support Equipment
2. MIL-H-22174 (WEPS)	Human Factors Data for Aircraft and Missile Systems
3. MIL-H-27894	Human Engineering Requirements for Aerospace Systems and Equipment

g. Interference

1.	MIL-E-6051C (USAF)	Electrical-Electronic System Compatibility and Interference Control Requirements for Aeronautical Weapon System
2.	MIL-I-6181D (2) (USAF)	Interference Control Requirements Aircraft Equipment
3.	MIL-I-16910A (3) (Ships)	Interference Measurements Radio, Methods and Limits 14 Kilocycles to 1000 Megacycles
4.	MIL-I-26600 (2) (USAF)	Interference Control Requirements Aeronautical Equipment

h. Installation

1.	MIL-I-8700 (ASG)	Installation and Test of Electronic Equipment in Aircraft, General Specification for
2.	MIL-E-0025366B (USAF)	Electric and Electronic Equipment and Systems, Guided Missiles, Installation of, General-Specification

i. Maintainability

1.	MIL-M-26512B (USAF)	Maintainability Requirements for Aerospace Systems and Equipment
2.	MIL-S-23603	System Readiness/Maintainability, Avionic Systems Design, General Specification for

j. Preservation and Packaging

1.	MIL-P-9024B (USAF)	Packaging, Air Weapon Systems Specifications and General Design Requirements for
2.	SPEC-BLTN-56 (USAF)	Preservation, Packaging, and Marking for Shipment Specifications

k. Provisioning

1. MIL-M-8910	Manuals, Technical, Illustrated Parts Breakdown, Preparation of
2. MIL-E-17362D (Ships)	Electronic Repair Parts Requirements, Procedures for Provisioning Technical Documentation and Stock Numbering

l. Quality Control

1. MIL-Q-9858 (2) (DOD)	Quality Control System Requirements
2. NPC-200-2- (NASA)	Quality Program Provisions for Space System Contractors
3. NPC-200-3 (NASA)	Inspection System Provisions for Suppliers of Space Materials, Parts, Components and Services
4. MIL-Q-21549A (WEPS)	Quality Assurance Program Requirements for Fleet Balistic Missile Weapon System Contractors

m. Reports

1. MIL-R-18301B (WEPS)	Reports, Contractors Engineering for Aircraft Avionics Equipment
2. MIL-R-18136A (2) (WEPS)	Reports Format and General Requirements

n. Sampling

1. MIL-STD-105C	Sampling Procedures and Tables for Inspection by Attributes
2. MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective
3. DOD-HDBK-106	Multi-Level Conditions Sampling Procedures and Tables for Inspection by Attributes
4. DOD- HDBK-108	Sampling Procedures and Tables for Life and Reliability Testing

o. Test Methods

1. MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment
2. MIL-STD-202 (C)	Test Methods for Electronic and Electrical Component Parts
3. MIL-T-4807A (USAF)	Tests, Vibration and Shock, Ground Electronic Equipment, General Requirements for
4. MIL-E-4970A (USAF)	Environmental Testing, Ground Support Equipment, General Specifications for
5. MIL-E-5272C (1) (ASG)	Environmental Testing, Aeronautical and Associated Equipment, General Specification for
6. MIL-T-18303 (WEPS)	Test Procedures, Preproduction and Inspection for Aircraft Electronic Equipment, Format for
7. MIL-STD-781	Test Levels and Accept/Reject Criteria for Reliability of Non-Expendable Electronic Equipment

p. Test Equipment

1. MIL-STD-415B	Test points and Test Facilities Design Standard for
2. MIL-T-945A (2) (DOD)	Test Equipment for Use with Electronic Equipment, General Specification
3. MIL-T-18306A (1) (WEPS)	Test Equipment and Test Bench Harness Requirements for Avionic Equipment and Guided Missile Contractor
4. MIL-T-21200D (ASG)	Test Equipment for Use with Electronic and Fire Control Systems General Specification for

q. Test Reports

1. MIL-T-9107 (2) (USAF)	Test Reports Preparation of

r. Training

1. MIL-T-4860C (USAF)	Trainers Operational Procedure, General Requirements for
2. MIL-T-26137B (USAF)	Trainers, Aircraft or Missile Engine General Requirements for
3. MIL-T-27382 (USAF)	Training Equipment, Subsystem Technical Data, Preparation of

4. MIL-T-26036 — Instructions for Preparation of Contractor-Prepared Specifications for Assembly Type Ground Support Equipment

5. MIL-T-27615 — Test Outline, Engineering, for the Inspection of Training Equipment, Requirements for the Preparation of

s. Vibration

1. MIL-STD-167 — Weight and Balance Data Reporting Forms for Guided Missiles

t. Wiring

1. MIL-T-713A (3) (DOD) — Twine and Tape, Lacing and Tying for Use in Electrical and Electronic Equipment
2. MIL-W-5088B (ASG) — Wiring, Aircraft, Installation of ASG
3. MIL-W-8160D (USAF) — Wiring, Guided Missile, Installation of General Specification for

APPENDIX D

EXAMPLE OF PLACING RELIABILITY REQUIREMENTS IN PROCUREMENT SPECIFICATIONS

Table D-1 contains examples of how reliability requirements are used currently and illustrates where they are placed in the specification. A comparison was made of specifications which originated at MSFC and several contractors (Boeing, S&ID, and Douglas). The left index refers to elements of a reliability program; the top index refers to the originator of the specification and the item for which the specification applies.

Table entries such as 3.2.21, refer to the particular section of the specification in which the requirement is stated. The first digit of the entry identifies the section of the specification according to the standard numbering format for specifications. For ease of reference this standard format is repeated below:

1. Scope
2. Applicable Documents
3. Requirements
4. Quality Assurance Provisions
5. Preparation for Shipment
6. Notes

TABLE D-1

SAMPLE RELIABILITY CONTENT

Agency Item Spec No.	Boeing Valve Assy 60B51441	Boeing Duct Assy 60B51004	Boeing Line Assy(GOX) 60B51404	Boeing Gimbal Duct Assy 60B83002	Boeing Valve Assy 60B43002
1. Reliability Program Plan					
2. Reliability Goal	3.2.5	3.2.13	3.2.13	3.3.14	3.2.20
3. Math Model	3.2.4 (f)	3.2.12 (f)	3.2.12 (f)		3.2.21 (f)
4. Failure Mode and Effect Analysis	3.2.4 (e)	3.2.12 (e)	3.2.12 (e)		3.2.21 (d & e)
5. Design Review	6.1.2	6.1	6.1	(9.0)*	6.2
6. Serial No. and Lot Tracability	3.7	3.5	3.5	(14.0)*	3.2.22
7. Failure Reporting	6.2.1.4	6.2.5	6.2.5	(10.3)*	6.3.1.3
8. Documentation	4.3.1.2	3.8	4.3.1.2	(3.0)*	4.6
9. Reliability Testing		4.5	4.5		4.5

* Chain reference to Boeing 60B00010

TABLE D-1

SAMPLE RELIABILITY CONTENT

Agency Item Spec No.	MSFC Amplifier R.F. 50M60034	MSFC Valve Control 10M01374	MSFC Saturable Reactor Assy 50M30825	MSFC Transformer Power Step-down 50M30826
1. Reliability Program Plan				
2. Reliability Goal				
3. Math Model				
4. Failure Mode and Effect Analysis				
5. Design Review				
6. Serial No. and Lot Tracability	3.8	3.10	3.4.11	3.4.6
7. Failure Reporting	4.1	4.1	4.4	4.3
8. Documentation				
9. Reliability Testing				

TABLE D-1

SAMPLE RELIABILITY CONTENT

Agency Item Spec. No.	S&ID Switch PWR. Transfer MC452-0026A	S&ID Valve Vent MC284-0030A	S&ID Timer Solid State MC456-0004A	S&ID Multiplexer Telemetry MC456-0007A	S&ID Quick Disconnect Hydraulic MC273-0031A
1. Reliability Program Plan	3.6.3	3.7.4	3.8		3.7.3
2. Reliability Goal	3.6.2	3.7.2	3.6.1	3.6.1	3.7.2
3. Math Model					
4. Failure Mode and Effect Analysis	3.6.5	3.7.4.2	3.9		3.7.5
5. Design Review	3.6.4	3.7.4.1	3.6.2	3.6.4	3.7.4
6. Serial No. and Lot Tracability	3.7			3.8	3.10
7. Failure Reporting					
8. Documentation					
9. Reliability Testing	4.7	4.7	4.7	4.7	4.7

TABLE D-1

SAMPLE RELIABILITY CONTENT

Agency Item Spec No.	Douglas Check Valve 7851859	Douglas Switch-Multipol Power Transfer 1A01826	Douglas Pump Hydraulic AUX-Motor Driven 7865752
1. Reliability Program Plan			
2. Reliability Goal			
3. Math Model			
4. Failure Mode and Effect Analysis			
5. Design Review			3.1
6. Serial No. and Lot Tracatility	3.1.9.2	3.3	3.2.6
7. Failure Reporting		4.1.3	
8. Documentation	3.1.10		3.1.6
9. Reliability Testing			

APPENDIX E

EXAMPLE OF DETAILED RELIABILITY REQUIREMENTS ON A COMPARATIVE BASIS

Table D-1 in the previous appendix (Appendix D) lists the placement of reliability requirements in current procurement specifications. Some difference in coverage was evident from the variation of entries when different originators are compared.

To further highlight this difference, Table E-1 compares the actual entries from several contractor specifications with the entries from a sample MSFC specification.

Table E-1 is a more detailed view of the specific entries of Table D-1. Excerpts from each of four different specifications (MSFC, Boeing, S&ID, and Douglas) are presented in the same order as in the previous table. Each excerpt is the actual text of the applicable reliability requirement.

The numbering scheme presented in both tables refers to the actual paragraph which is being referenced. For ease in reference, the standard numbering format for specifications is presented below:

1. Scope
2. Applicable Documents
3. Requirements
4. Quality Assurance Provisions
5. Preparation for Shipment
6. Notes

TABLE E-1

DETAILED RELIABILITY CONTENT

This table contains excerpts from actual specifications. The arrangement of topics (Reliability Program Plan, Reliability Goal, etc.) is in the same order as the left index of the previous table, D-1. The code letters A, B, C, and D are used to designate each of the following specifications:

CODE	ORIGINATOR	DOCUMENT NO.	
A	MSFC	10M01374	Valve, Control, Specification for
B	Boeing	60B51404	Line Assembly, Inboard Engine, GOX
C	NAA	MC284-0030A	Valve, Vent-Liquid Propellant Tank
D	Douglas	7851859	Valve, Check, Fuel Tank Pressurization

---

1. Reliability Program Plan

A) ------

B) ------

C) 3.7.4 Reliability Program

The reliability program of the valve shall be in accordance with Specification MA0118-002, Category II.

D) ------

2. Reliability Goal

A) ------

B) 3.2.13 Reliability

The line shall have an inherent reliability goal of .9999343 which specifies the probability of successfully accomplishing the critical function during the 2.6 minutes of launch and boost operation of the S-IC stage.

The critical function is to conduct LOX tank pressurant (GOX) flow without line rupture.

Successful accomplishment of the above noted critical function is defined as operation within the environmental and performance parameters specified in the design requirements, Section 3, of this drawing.

C) 3.7.2 <u>Reliability Quantitative Requirements</u>

The reliability quantitative requirements shall be .9998 for 10 minutes in flight time with a confidence of 90 percent.

D) ------

3. <u>Math Model</u>

A) ------

B) 3.2.12 <u>Design Analysis</u>

The supplier shall furnish the procuring activity a positive reproducible of a design analysis for the line 2 weeks prior to critical design review. The design analysis is not limited to, but shall include the following:

(a) ......

(b) ......

(c) ......

(d) ......

(e) ......

(f) Probability of success analysis

C) ------

D) ------

4. <u>Failure Mode and Effects Analysis</u>

A) ------

B) 3.2.12 <u>Design Analysis</u>

The supplier shall furnish the procuring activity a positive reproducible of a design analysis for the line 2 weeks prior to critical design review. The design analysis is not limited to but shall include the following:

(a) ......

(b) ......

(c) ......

(d) ......

(e) Failure mode and effect analysis

(f) ......

C) 3.7.4.2 <u>Failure Mode Analysis</u>

Failure mode analysis of the valve shall be conducted by the supplier in accordance with Specification MA0118-008, Category II.

D) ------

5. <u>Design Review</u>

A) ------

B) 6.1 <u>Design Reviews</u>

Design reviews shall be scheduled and conducted at appropriate phases of the supplier's design development to evaluate his design progress in request to the product requirements.

C) 3.7.4.1 <u>Design Review</u>

The supplier shall participate in a design review program in accordance with Specification MA0118-003, Category II.

D) ------

6. Serial No. and Lot Tracability

A) 3.10 Product Marking

Product marking shall be in accordance with Standard MIL-STD-130.

B) 3.5 Serialization/Lot Identification

Serialization shall be accomplished to differentiate between lines. The supplier shall be required to provide the procuring activity, documentation of his serialization/lot identification plan for approval. In the event the procuring activity takes exception to the suppliers serialization/lot identification plan, the supplier will be so advised and the exception resolved through coordination.

C) ------

D) 3.1.9.2 Serial Number Requirements

The vendor shall identify each article with a serial number using methods of application and location of marking per Paragraph 3.1.9 above. These serial numbers shall be reflected on Douglas receiving documents. Configuration control must be established by the vendor so as to describe a serial number as released in respect to sequence of manufacture and subsequent change or modification.

7. Failure Reporting

A) 4.1 Inspection System

The inspection system shall be in accordance with NASA Publication NPC 200-3 unless otherwise specified by the procurement document (see 6.2). The inspection plan as referenced in NPC 200-3 shall be submitted to the procuring activity for approval when so specified by the procurement document (see 6.2). The procuring activity reserves the right to perform any inspection deemed necessary to assure supplies and services conform to prescribed requirements.

B) 6.2.5 Failure Records

All failures occurring during functional and acceptance testing and the corrective action taken, shall be recorded by the supplier and reported to the procuring activity. The Unplanned Event Record (UER) form (Fig. 8) or its equivalent shall be used for this purpose.

C) ------

D) ------

8. Documentation

A) ------

B) 4.3.1.2 Documentation

(a) The supplier shall provide the procuring activity with the proposed test program in accordance with 3.8, two months in advance of the test schedule dates for comment and approval. The test program shall include the following: detailed test procedures; test schematics including all instrumentation and control equipment; list of test equipment including measuring tolerances; name and location of test facilities including subcontractors, if applicable. Written approval of the test program shall be made by procuring activity prior to test initiation.

(b) The supplier shall furnish data which shall conclusively prove that the requirements of each paragraph of Section 3 have been met.

(c) The supplier shall submit monthly status reports in accordance with 3.8 and identified by a supplier report number which shall show the status of testing. These reports shall include the following: progress against the test schedules, general results of accomplished tests, changes pertinent to the test program, and scheduling of subsequent tests. Any occurrence that will have significant actual or potential effect on the accomplishment of scheduled testing shall be reported immediately to the procuring activity.

C) ------

D) 3.1.10 Requirements for Data

The vendor data articles which define the requirements for engineering drawings and associated lists, materials research and process engineering data, and the requirements for product support data (service, spare parts lists, technical publications, etc.) as applicable, will be furnished with the purchase order or contract to which this document is applied.

9. Reliability Testing and Test Program

A) ------

B) 4.5 Reliability Tests

4.5.1 Requirements

4.5.1.1 General

(a) Three lines shall be tested in accordance with the requirements of this test.

(b) The purpose of this test is to determine the margin of safety in the design and to gain a higher level of confidence in the component.

(c) The supplier shall provide the procuring activity with two weeks advance notice of the test schedule dates in order that a representative may be present if the procuring activity so desires.

(d) Acceptance tests shall be conducted prior to the Reliability Tests in accordance with Paragraph 4.4.

4.5.1.2 Documentation

The supplier shall provide the procuring activity with data and reports in accordance with Paragraph 4.3.1.2 including time and cycle data. If failure occurs, the circumstances of failure shall be reported.

4.5.1.3 Mounting

The line and its vehicle supporting bracketry (4.1.1e) and flight seals (Paragraph 6.4) shall be installed in a test fixture simulating an angular misalignment, which produces the greatest deflection of the flexible members (3.2.8). The test fixture shall balance the end loads. Vibration inputs shall be to the vehicle supporting bracketry.

4.5.2 Tests

(a) The line shall be pressurized to operating pressure, (3.2.4) with the line and pressurizing media stabilized at 500°F.

(b) The random vibration of 0.6 g^2/cps as one input over the frequency interval from 20-2000 cps in each of the three mutually perpendicular axes, is operating level. Begin the test at operating level +25% for 5 minutes in each of the three axes. Then at operating level +50% for 5 minutes in each of the three axes. Then at operating level +75% for 5 minutes in each of the three axes. Then at operating level +100% for 5 minutes in each of the three axes.

If random vibration generators are not available to reach the prescribed levels, then level capability will be stated and submitted for approval.

(c) After tests have been completed, and if failure has not occurred, the line shall then be tested for leakage by placing it under water and pneumatically pressurizing it for 5 minutes at the adjusted proof pressure, 3.2.5.

(d) Degradation or change in performance that could in any way prevent the article from meeting the specified requirements shall constitute a failure and shall be reported.

(e) Specimen #2 Test

(1) Initiate test at operating level of failure of specimen #1. Continue until test is completed. If failure does not occur on second specimen, third specimen shall be tested at the random vibration at operating level from 20-2000 cps for 45 minutes in either V - V axis or flight direction axis.

(2) If failure does not occur on specimen #1, repeat tests on specimens #2 and #3.

C) 4.7 Reliability Tests

Reliability tests shall consist of:

(a) Quality maintenance tests

(b) Ultimate stress tests

4.7.1 Quality Maintenance Tests

4.7.1.1 Test Specimen Selection

For new production test specimens (designated as specimens number 5, 6, 7, and 8) shall be selected by S&ID Reliability for the quality maintenance tests. These specimens shall be selected and the tests shall be performed at specified intervals throughout the production run.

4.7.1.2 Test Plan

The supplier shall subject the test specimens to the quality maintenance tests of Table V. The performance and electrical tests of Paragraphs 4.8.3.3, 4.8.3.5, 4.8.4.1, and 4.8.4.3 shall be performed at room ambient conditions 48 hours prior to the start of any environmental test indicated in Table V. The first specimen selected for quality maintenance tests shall be tested as specified for specimen number 6 in Table V. The order shall be maintained until all test sequences for all test specimens are completed.

TABLE V

QUALITY MAINTENANCE TESTS

NAME OF TEST	PARAGRAPH NUMBER	SPECIMEN NUMBER / TEST SEQUENCE 5	6	7	8*
Acceptance tests	4.6.1	1	1	1	1
Humidity test	4.8.6	2	4	5	
Shock test (mechanical	4.8.7	3	5	6	
Explosion proof test	4.8.8	4	6	7	
Salt Spray test	4.8.5	5	7	8	
High temperature test	4.8.9	6	8	9	
Low temperature test	4.8.11	7	9	2	
Thermal shock test	4.8.10	8	2	3	
Vibration test	4.8.12	9	3	4	
Acceleration test	4.8.13	10	10	10	2
Cycling test	4.8.14	11	11	11	3

NOTE: Each specimen shall be subjected to the tests in the order indicated by the numerals in the corresponding columns.

* Specimen number 8 shall undergo the cycling test of 4.8.14 for a total of 60 cycles.

4.7.2 Ultimate Stress Tests

4.7.2.1 Test Plan

The supplier shall subject the quality maintenance test specimens to the ultimate stress tests shown in Table VI after completion of the quality maintenance tests of Table V. Before the ultimate stress tests and after each test level, as shown in Table VI, the specimens shall be subjected to the performance and electrical tests of Paragraphs 4.8.3.3, 4.8.3.5, 4.8.4.1, and 4.8.4.3.

TABLE VI

ULTIMATE STRESS TESTS

Specimen Number	Test	Paragraph Number	INCREMENTAL INCREASES	
			Spec. +20%	Spec. +40%
1.	Vibration (frequency cycling)	4.8.12.3	x	
2.	Vibration (frequency cycling)	4.8.12.3		x
3.	Vibration (frequency cycling)	4.8.12.3	x	
4.	Vibration (frequency cycling)	4.8.12.3		x

NOTE: The vibration tests of Table VI shall be run at -100 degrees F only, with 4 frequency cycles in each axis.

D) ------

LIST OF DEFINITIONS

Component - A combination of parts which cannot be disassembled in the field without invalidating functional integrity. Examples: valve, relay, actuator, gyro, turbopump, and accelerometer.

Critical Items List - A listing of vehicle/complex components whose failure results in the probability of vehicle/complex loss.

Criticality Ranking - The numerical product of the system loss probability for a component's applicable failure mode, the component failure mode frequency ratio and the items unreliability associated with the critical failure mode (or modes).

Design Review - A progressive review, starting after the design study and continuing through the prototype stage. Provides an assessment of reliability and reliability trends by use of applicable tests and prediction techniques.

Documentation - Information that is generated to record data required for control of design, production, procurement, maintenance, and supply of material, e.g., drawings, specifications, handbooks, manuals, etc.

Type I Documentation - Documentation requiring NASA approval.

Type II Documentation - Documentation required for coordination, surveillance, and information.

Type III Documentation - Defined as the documentation requiring preparation and retention by the contractor, being made available to authorized representatives of the NASA for review, upon request.

Engineering Confidence - Engineering confidence is that confidence, established through the qualitative analysis and evaluation of design, design parameters, fabrication.

Estimate - An estimate is a value computed from a sample which is used as a "best guess" of the value of a population parameter.

Failure - A failure is unsatisfactory equipment performance as determined by judgment or performance measurement, where it is implied that performance is outside proper operational specification limits. Failure must be defined in detail for each specific analysis.

Failure Mode and Effect Analysis - An analysis of possible modes of failure, their cause, effects, expected frequency of occurrence and means of elimination.

Failure Reporting and Corrective Action - A systematic and comprehensive method of reporting all failures and a plan for implementing corrective action as a result of these failures.

Failure Analysis - The study of a specific 'failure' to determine the circumstances which caused the failure, and to arrive at a course of corrective action to prevent recurrence.

Failure Mode - The manner in which hardware (such as 'assembly', 'component', or 'piece part') fails.

Interface - The physical and functional interaction between two 'piece parts', 'components', 'subsystems', 'systems', or any mode of contact between two or more elements, including the crew, during any operation of a system.

K Factor - A K factor is an adjustment of data expressed in a multiplicative form.

Milestones - Any significant event in the design and development of a space system or in the associated reliability program which is used as a control point for measurement of progress and effectiveness or for planning or redirecting future effort. Reliability program milestones should be identified in the Reliability Program Plan.

Monitoring - The continual checking of a reliability program to insure that all phases of the program are satisfactorily implemented and are continued throughout its duration.

Part - A part is an item of equipment, usually thought of as small and purchased from a vendor, which is normally replaced rather than repaired when it fails.

Performance - Performance is a general term applied to the output of any item or equipment.

Primary Failure - Failure which occurs by chance in an accidental, casual or haphazard manner.

Quality Assurance - A planned and systematic pattern of all actions necessary to provide adequate confidence that the end items will perform satisfactorily in actual operations.

Reliability - Reliability is the probability that a system will perform satisfactorily for at least a given period of time when used under stated conditions.

Reliability Apportionment - The assignment (by derivation from the contractual reliability requirement) of reliability goals to systems, subsystems and components within a space system which will result in meeting the overall contractual reliability requirement for the space system if each of these goals is attained.

Reliability Assessment - An analytical determination of numerical reliability of a system or portion thereof. Such assessments usually employ mathematical modeling, use of directly applicable results of tests on system hardware, and some use of estimated reliability figures.

Reliability Demonstration - Statistically designed testing, with specified confidence level, to demonstrate that an item meets the established reliability requirement.

Reliability Element - That portion of a reliability program that pertains to a single phase of the reliability program.

LIST OF DEFINITIONS CON'T

Reliability Goal - A reliability goal is a preset reliability objective determined by program management from a consideration of operational needs, state-of-the art capability, cost, time, etc. The goal can be a minimum acceptable level, an expected program accomplishment, or an idealistic target.

Reliability Model - A reliability model is a mathematical relationship in formula or pictorial form which expresses the interrelationship between a system failure pattern and those of subdivisions of the system. In place of subdivisions, one could also use failure modes or mechanisms, or both.

Reliability Prediction - An analytical prediction of numerical reliability of a system or portion thereof similar to a reliability assessment except that the prediction is normally made in the earlier design stages where very little directly applicable test data is available.

Reliability Program Plan - A document that details the approach and stepwise procedure by which a contractor shows his intent of compliance with the reliability provisions of the contract.

Reliability Specification - A reliability specification is a statement of reliability levels which must be achieved. Such specifications can occur in contracts or in project plans, or both.

Secondary Failure - Failure due to the failure or malfunction of another item. Secondary failure is one which occurs as a by-product of an independent failure.

Subsystem - A combination of 'piece parts', 'components', and 'assemblies' joined together to perform a specific function within a 'stage', 'module', IU, or LES.

System - Any combination of 'piece parts', 'components', 'assemblies' and 'subsystems' joined together to perform specific operations or functions.

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